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ABSTRACT

This paper examines how the revolution in human thinking, with the smaller revolution in astronomy begun by Nicolus Copernicus, has plunged science educators into the new Age of Information. Examples which illustrate this development and change in human thinking (from Copernicus' time to the present) are provided from such disciplines as astronomy, geology, physics, chemistry, psychology, the biological sciences, mathematics, sociology, and information science. These examples focus on such areas as the thermodynamics of open and closed systems, the second law of thermodynamics, energy, matter, heredity, development of the entropy concept, and the relationship between entropy, order, and life. The paper concludes by pointing out that unlike the old, classical laws of thermodynamics, the new laws of information indicate that information, genetic or unlearned: (1) exists in the arrangement of matter; (2) regulates time, organizes matter, and controls energy flow; (3) is inversely related to entropy; and (4) is created and destroyed. The reward of learning about how the evolution in human thought is propelling us into an exciting future is a benefit for adolescents examining this material. (JN)

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SCIENTIFIC LITERACY:
WHERE DID IT COME FROM?
WHERE IS IT GOING?

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This paper is an examination of the big scientific revolution, centered around the 1850's. The examination seeks to show how this revolution in human thinking, with the smaller revolution in astronomy, begun by Copernicus, has plunged science educators into the New Age of Information.

This paper mentions only a few inquiring minds from a list of more than 1,500 prominent scientists.[1] The reader is urged to investigate the remainder on his own. The reward is that adolescents are very enthusiastic when learning about the evolution in human thought that is propelling us into an exciting future.

Nicolus Copernicus (1473 - 1543) was not alone in taking the Earth (and humans) from the center of the Universe in human conceptualization, but he did begin a quest for a new scientific literacy, which is still with us today. Even with the works of Galileo (1564 - 1642) and Newton (1642 - 1727) to follow, Copernicus' banned book was not cleared from "the list" until 1835.

However, the number of inquiring minds did not cease to grow. From 1500 forward, such men as Agricola (1494 - 1555), Steno (1638 - 1686), Buffon (1707 - 1788), Hutton (1726 - 1797), Humboldt (1769 - 1859), and others would look at the planet Earth from an inquiring perspective. Their work would lay the foundations for a new view of the Earth's age, its composition, structures and evolutionary transformations. Indeed, the newly developing field of Geology would lead to Charles Lyell's

(1797 - 1875) three volume work, The Principles of Geology (1830 - 1833), an influence on Charles Darwin (1809 - 1882), and Lyell's marriage of Darwin's findings with the ideas from the new discipline of Geology in Lyell's 1863 book, The Antiquity of Man.

However, before entering further biological considerations, the revolutions in two other disciplines should be mentioned. For they added greatly to the big scientific revolution of the 1850's. In areas of energy and matter, it must be noted how the disciplines of physics and chemistry would also leave an important mark on this time period.

In the 1850's Rudolf Julius Emmanuel Clausius (1822-1888) decided to use the terms energy and entropy to describe two of the most important laws science had discovered about natural phenomena. Carnot (1796-1832) had already published his work On The Motive Power Of Fire in 1824 when the idea of a caloric was still in vogue and the terminology used. And by 1834 Clapeyron (1799-1864) had also worked with steam locomotion devises. Both men were close to stating the second law of thermodynamics, and depended on the prior steam engines of Watt (1736-1819), and the works of many other men.

But it was Clausius who initiated the broadest, most general conceptual statements of the two laws:

1. The energy of the universe is constant.
2. The entropy of the universe tends to a maximum.

The revolution and evolution in energy and entropy concepts was begun and is still with us today.

Lord Kelvin (William Thomson) (1824-1903) also contributed significantly to the mid ninteenth century's revolution in science. His absolute zero temperature scale, and his recognition of the fact that heat is finally dispersed from all energy transformations helped reinforce the second law and the entropy concept.

Helmholtz (1821-1894), too, worked with energy and the human senses. Maxwell (1831-1879) contemplated energy and molecular motion, as well as electromagnetic theory. His famous "demon" helped weave a cohesive concept of energy and entropy, which would eventually lead to a link between entropy and information.

Dimitri Ivanovich Mendeleev (1834-1907) led the evolution in thought about matter. Although Chancourtois (1820-1886) and Newlands (1837-1897) had both found some order among the elements, it was Mendeleev who published the first acceptable periodic table. Chemistry was adding its thrust to the big scientific revolution.

A new scientific literacy was born for astronomy, geology, physics and chemistry. Half of the big scientific revolution was in place. The physical sciences were setting human thought on a new course of action. The other half of the new scientific literacy would come from the biological sciences.

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Darwin's book, The Origin of Species, was finally published in 1859, after he spent fifteen years perfecting his manuscript. Alfred Russell Wallace (1823-1913) arrived at the same theory at about the same time. He apparently put the theory to paper in a couple of days, then

sent the paper off to Darwin. Both men had been influenced by Malthus' (1766-1834) Essay on Population and Lyell's geological work mentioned earlier.

However, neither Darwin nor Wallace knew about the inherited characteristics of all living things, nor how that knowledge might help their theory. Ironically, the science of heredity would be born alongside the science of evolution.

Working by himself in the 1850's Gregor Johann Mendel (1822-1884) began his investigations with pea plants. The genetic-biological evolution theory was underway, adding enormous fuel to the big scientific revolution.

Experimental psychology was born from physiologists and men of medicine. Ernst Heinrich Weber (1795-1878) and James Braid (1795-1860) laid the foundations for the new science of psychology. Their beginnings in the mid-nineteenth century would lead to the work of Charcot (1825 -1893) in hypnosis and hysteria. Freud (1856-1939) was a student of Charcot.

The work of Weber and Braid preceeded that of Helmholtz, mentioned earlier. William James (1842-1910), the father of American Psychology, had studied under Helmholtz in Europe. Hall (1846-1924) was a student of both James and Helmholtz. Hall pioneered child psychology and the science of teaching in the United States.

This increase in scientific literacy about life on earth would not be complete without mentioning Pavlov (1849-1936). He read Darwin's work, studied under Mendeleev, and advanced physiological psychology.

Like the ideas of evolution and heredity, the concepts from the new science of psychology would contribute to the big scientific revolution as much as the ideas from the physical sciences had contributed. Yet, the 1850's revolution was not complete. One other discipline must be added to the newly emerging literacy; that of sociology.

Doing science had become much more socially acceptable by the 1850's. By then science had fought its way through the Renaissance. For 550 years, from approximately 1300, the earlier experimenters strove to get their new methods and ideas accepted. Finally, in 1831 the British Association for the Advancement of Science was founded. The word "scientist" originated at Glasgow in 1840. And the American Association for the Advancement of Science was begun in 1848.[2] By this time Auguste Comte (1798-1857) had initiated a new science he called sociology. In his writings on "positivism", he saw a positive stage of social evolution depending on logic, observation, experimentation and scientific laws. To Comte the study of social problems was just beginning and he wanted the new discipline to be scientific.

In 1848 Marx (1818-1883) and Engel (1820-1895) collaborated on the Communist Manifesto. Both men had written other works before the manifesto, and both continued to publish in the years following the manifesto. Needless to say, they belong to the big scientific revolution, and their impact too is still with societies today.

Finally, such men as Josiah Willard Gibbs (1839-1903), an American who helped found chemical engineering and has been called a forerunner of the American, technological revolution, helped shape our society.[3].

With the above knowledge about energy, matter and life in place, the General Electric Company initiated a scientific research laboratory in 1900. By then, Alexander Graham Bell (1847-1922) and Thomas Alva Edison (1847-1931) had already patented their first inventions (1876 and 1868, respectively).

Our United States was thus destined to become a scientific, technological society of the highest order on Earth. The new scientific literacy had been born from the big scientific revolution. Science education had become a necessity to maintain the kind of society we had become.

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Today there are tens of thousands of applied scientists, research scientists and science educators at work in the United States, not to mention the other nations on Earth. Today there are millions of people engaged in the scientific enterprise and scientific literacy, compared to a few thousand a century ago.

Since the big scientific revolution, there have been more discoveries and more engineering feats than in all the past million years of human evolution.

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Since the big scientific revolution evolved from very diversified and very separated disciplines, science was split. Science was not whole in its concept of natural phenomena. The studies of astronomy, geology, physics, chemistry, biology, psychology, sociology and technology were here and there linked as new interdisciplinary courses slowly emerged. But it would take about a hundred years for the scientific concept of natural phenomena to become whole.

That wholeness would come about because of the theoretical work done to merge the life sciences with the physical sciences. For that to happen, three areas of thought would have to be employed:

1. Humans, as all of life on Earth, would have to be seen as a part of nature. As long as life was viewed as estranged from the laws of thermodynamics, no merger was possible. Somehow the Second Law and the entropy concept had to take life into account. Two new ways of looking at natural phenomena were needed.

2. Information became unavoidably linked to the entropy concept and to life.

3. Systems were classified to include both animate as well as inanimate kinds.

With the advent of information theory and the classification of systems, a new scientific literacy is in place, with humans seen as a part of natural phenomena.[4]

Early in the twentieth century Darwin's theory of biological evolution had already caused fifty years of rumbling, and Mendel had experimented with the mechanism whereby evolution could function. Finally it came to be realized that all living things use energy and matter to grow and go. And in so doing, for a time, their systems become less randomized and more organized. With the rise of experimental embryology and developmental anatomy, vitalism finally lost its vogue in biology. Maxwell's demon could be looked at in a new light--an intelligent being tampering with the normal flow in a system.

Leo Szilard (1898 - 1964) published the explanation for Maxwell's paradox in a German Physics journal of 1929, (Zeitschrift fur Physik, 53, 840-856). The now famous article was not reprinted in English until 1964, (Behavioral Science, Vol. 9, No. 4, October). The translated title of the article is, On The Decrease Of Entropy In A Thermodynamic System By The Intervention Of Intelligent Beings.

World War II brought Szilard to the United States, as it did so many great European scientific minds. His interest in atomic energy pulled him together with Einstein (1879 - 1955), Fermi (1901 - 1954), and other important members of the Manhattan Project.

After World War II Szilard's interest remained with radiation considerations, and like so many atomic scientists, he became politically involved because of an understanding of radiation's detrimental effects. He worked in biophysics and biochemistry, and left the

evolution of the entropy, information and systems theorizing to the writings of others.

Thus, the first half of the twentieth century gave its greatest acclaims to the work being done on the nucleus of atoms; perhaps because of two world wars and the very rapid rise of sophisticated military technology. However, soon after World War II interest in the entropy concept was to swell again in Europe, and entropy considerations were to blossom in the United States as never before.

Claude Elwood Shannon (1916 -) is the American applied mathematician who made the postwar attempt to link information theory with the entropy concept. Though Shannon is referred to as fathering information theory, he was not alone in his thinking. The year before his important paper appeared, the American mathematician, Norbert Wiener (1894 - 1964) had published his most thoughtful book, Cybernetics. Whereas Shannon was primarily concerned with entropy and communications engineering, Wiener realized that the control over any system's behavior, be it an organism or a mechanism, involves communication.

Living systems were unavoidably being considered in the information and entropy area, just as Maxwell and Szilard had foreseen.

In the same decade added impetus was given to the life and entropy considerations by Erwin Schrodinger (1887 - 1961). He was an Austrian physicist and philosopher who is still popular for his book, What is Life? Schrodinger saw that in the evolution of life there was a tendency for higher and higher organization and complexity and flexi-

bility. Unlike the ordered and rigid and low-entropy systems of the crystals, life's systems have reduced entropy in a manner which allowed for change. From the lowly housefly and the termitary of the termites, to the highly organized brains of humans and the cities they build, Schrodinger saw life as going from disorder to order.

Schrodinger's book may be one of the earliest popular accounts in English of the relation between entropy, order and life. He saw life as a massive movement at striving to reduce entropy. Or, as he put it, the living organism "...feeds on negative entropy."

These last two words were to be joined later by an important American theoretical physicist. Leon Brillouin (1889 - 1969) called the human trend to put more and more efficiency, order and organization into their information-communication-knowledge systems the negentropy process. Whereas entropy meant going from a more ordered state to a more random state, negentropy meant going from a more disordered state to a more organized one.

In the same decade of the forties, when Schrodinger, Wiener, Shannon and others were contemplating and joining life and information to the entropy concept, two other contemporary men were in their embryonic stages of writing about thermodynamics and the entropy concept.

Ilya Prigogine (1917 -) was in Europe, already published by 1947, deeply interested in minimum entropy production, and, for his work on the subject, destined to win the Nobel Prize thirty years later.

Robert Bruce Lindsay (1900 -) was in the United States writing physics textbooks on statistical mechanics, thermodynamics, and other material which would eventually lead to the deliniation of his "Thermodynamic Imperative." Lindsay explained how humans could have guidelines for their behavior--a foundation for their ethics--based on what science had discovered about natural phenomena, the laws of thermodynamics and the entropy concept.

In the 1940's philosophizing about entropy and living systems was way ahead of the mathematicians' capabilities, so many physicists and chemists thought therefore that they had the only right of domain over the entropy concept. Biologists, sociologists and other behavioral scientists seemed reluctant to wed the entropy concept with the knowledge in their own fields.

The classical thermodynamics of the 1850's dealt with isolated or closed systems and was sufficient in university courses and industries for almost any technological advancements. So why extend the role of thermodynamics? In 1961 Prigogine's Thermodynamics of Irreversible Processes was published. He realized that most thermodynamic systems were not of the closed kind, exchanging only energy with their environments. Prigogine was quite aware that living systems were open systems, exchanging both energy and matter with their exteriors.

With funding from the United States Air Force, General Motors Corporation, General Electric, and others, Prigogine has been able to continue his mathematical work with open systems. He was also supported by the Free University of Brussels, the University of Chicago, North-

western University, and the University of Texas at Austin, where he is currently the director of the Ilya Prigogine Center for Statistical Mechanics and Thermodynamics.

Prigogine's quantitative analysis, comments, acknowledgements, and extensive bibliography can be found in his work, Non-equilibrium Statistical Mechanics, published in 1962. His bibliography reveals the massive amount of work Prigogine had to review from World War II until that time.

Lindsay's completed work on the non-mathematical treatment of the total entropy concept also appeared in the early sixties. The Role of Science in Civilization was first published by Harper and Row in 1963. But Lindsay's ideas about entropy and his phrase "The Thermodynamic Imperative" are found in his earlier article, "Entropy Consumption and Values in Physical Science," which appeared in the American Scientist, pages 376-385, in 1959.

At the time the article was published, Lindsay was Dean of the Graduate School and Professor of Physics at Brown University. The article has no bibliography, but a follow up article by Steven Polgar at the University of California at Berkeley has an extensive bibliography. "Evolution and the Thermodynamic Imperative" was published in Human Biology, on pages 99-109, in 1961. The article reveals the amount of non-mathematical writing that was done on life and entropy between World War II and the early sixties.

Polgar's literature list stretches from Johnstone's book, The Mechanism of Life in Relation to Modern Physical Theory to Lindsay's article

mentioned above. What makes Polgar's article unique, and often quoted, is the fact that it consolidated the thoughts of so many great men in biology, sociology, anthropology, and evolution.

After a hundred years since the big scientific revolution, and many chasms between the physical and the biological sciences, science had become more than simply a way to investigate natural phenomena. Science had made its view of natural phenomena whole. Science had placed humans and all of life in natural phenomena. And with the new wholeness came thoughts of values and an entropy ethic from what had been discovered.

In 1968 Ludwig von Bertalanffy's (1901 - 1972) book, General System Theory was published. Isolated, closed and open systems would be further classified.

Blum's Times Arrow and Evolution was reprinted for the sixth time in 1970. It contains a new chapter on "Order, Negentropy, and Evolution."

In 1971 Prigogine was published again with a member of the General Motors Research Laboratories. The Kinetic Theory of Vehicular Traffic book applies his open systems, non-equilibrium, irreversible statistics to a distinctly human activity.

Also in 1971, Bent's article was published in the October issue of Chemistry. Bent's "Haste Makes Waste--Pollution and Entropy" article ties maintenance of the environment to the entropy concept.

In 1972 Gatlin's book Information Theory and the Living System was published, with many examples of entropy reduction in human behavior

via information storage.

Prigogine and others published again in 1972. Their two part article on the "Thermodynamics of Evolution" was published in the November and December issues of Physics Today in 1972. The article takes into account Prigogine's work on open systems, entropy flow, non-equilibrium order, and the rise of knowledge about the DNA code. Their subtitle is "The functional order maintained within living systems seems to defy the Second Law; non-equilibrium thermodynamics describes how such systems come to terms with entropy." The authors show that through the organization of macromolecules which are not static "This primitive memory effect makes these structures capable of storing information accumulated in a remote past." And they show further "...that nucleic acids are a necessary prerequisite for self-organization because they possess the ability to act as templates."

In 1973, ten years after its original printing, Lindsay's The Role of Science in Civilization was reprinted. His ethical code remained the same, "...consume as much entropy as possible, in order to combat the natural tendency for entropy to increase and for order in the universe to be transformed into disorder, in accordance with the second law of thermodynamics."

Also, in 1973, Lehninger's book Bioenergetics was printed for the second time. The book concisely related energy and entropy to information as well as closed and open systems. Lehninger stated that, "Just as thermodynamics is the first and most basic way of analyzing processes

involving inanimate matter, so is it fundamental in analyzing the behavior of living organisms."

Although the Project Physics Reader #3 had mentioned entropy considerations as early as 1970, it was between 1973 and 1977 that the entropy concept was placed in high school and college freshman science textbooks. But then the concept was only on a very elementary level, rarely mentioning biological or human behavioral considerations.

Saperstein's college freshman text, Physics: Energy in the Environment of 1975 was the first to expand the entropy concept with many new ideas and examples. In his section on "Entropy as a Measure of Randomness", he explains; how "randomness increases with uncertainty", "entropy in history", how "entropy can decrease in non-isolated systems", "entropy in agriculture", and finally in "entropy, information, and noise, how "noise is entropy."

The above mentioned people were not alone in their writings and considerations about the entropy concept. Kubat and Zeman (editors) published their compiled articles in 1975. The Entropy and Information in Science and Philosophy volume contains eighteen articles on entropy concepts, ranging from physics through all the disciplines to information theory and philosophy. The collected papers bring together some of the great minds of both Eastern and Western nations.

In 1976 Fox's "The Recolored Mentality---Ethical Lessons From Science" was published in the September issue of The Science Teacher. He stated that "The Second Law of Thermodynamics also poses an interesting dilemma

for students. Man's physical body and his social aspirations are anti-entropic, representing states of higher organization and concentration of potential energy in a sense." He further proposes that "...students build hope in something ethically durable." Fox's purpose in writing the article was to show that "There are ethical lessons arising from conceptual science..." and that "These lessons may properly be delt with in secondary school science."

By March of 1977 the Georgia Conservancy reprinted its Wolfcreek Statement, and the United States was on its way to having a new Energy Department. An effort would be made on a national level to slow down the irretrievable loss of energy.

Slowing the speed at which energy, matter, or information is lost results in reducing entropy. But Bent did not like the government's use of the term "energy conservation." The Science Teacher published his article, 'Entropy & The Energy Crisis" in May 1977. Bent wrote,"SavEnergy, we are told. There's an energy crisis. But energy is always saved. By definition....There is no need to try to conserve energy. Energy is always conserved." Since experimental evidence shows that energy is neither created nor destroyed, Bent was taking issue with the government's term and the national energy policy, and not with the entropy concept. He wrote, "What we don't need is a national energy policy. What we do need is a personal entropy ethic."

By the fall of 1977 Bent was on the road, holding workshops for the Office of Science Education of the American Association for the Advancement of Science, with financial support from the National Science Foundation.

His Thermodynamics, Art, Poetry, and the Environment workshops continued into the spring of 1978, and they covered: "...development with students of (1) a scenario for a film that, projected backwards, dramatizes time's arrow; (2) a script for a play on the theme The Entropy Ethic; (3) a critique of the commandment, Thou shalt not unnecessarily create entropy; (4) analogies between science and the arts; (5) statistical date (hand- or computer-generated) that illustrate Boltzmann's Energy Distribution Law."

Also, in the fall of 1977, Stein added to Polgar's dimension by tying energy use to building design in his book Architecture and Energy. He wrote, "Buildings designed to overuse energy penalize everyone who needs energy for survival." Thus, just as Polgar had suggested, human structuring was brought under the umbrella of thermodynamics and ethical ideas, along with many other behavioral considerations.

In the fall of 1977 Ilya Prigogine was awarded the Nobel Prize in Chemistry, for his work on non-equilibrium thermodynamics. On January 1, 1978 Prigogine's voice ushered in the New Year over WOAI FM Radio in San Antonio, Texas. He spoke about his Nobel Prize and the concept of minimum entropy production. He closed by stating that he saw the concepts unraveling as being "the wave of the future."

During the past seven years, since 1977, the books and articles on entropy have spanned the disciplines. The proliferation of the new paradigm has flowed like food from the cornucopia of human knowledge.

The wave of the future has its arrow pointed. Scientific literacy via science education must flow with "Man's New Dialogue With Nature."[6.]

Science is whole in its view of nature.

People are now seen as a part of nature.

The systems are classified and ready to be taught.

The information age is here.

Time, information, matter and energy (the T.I.M.E. acronym) are all related to entropy, and all must be properly managed to thwart the tendency of the Second Law.

Within this new wave, teachable ethics do indeed exist. For unlike the old, classical Laws of Thermodynamics, the new Laws of Information point to possibilities ready for research:

1. information, genetic or learned, exists in the arrangement of matter.
2. information, genetic or learned, regulates time, organizes matter and controls energy flow.
3. information, genetic or learned, is inversely related to entropy.
4. information, genetic or learned, is created and destroyed.

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